THE UNIVERSITY of TULSA

TUFFP

TULSA UNIVERSITY FLUID FLOW PROJECTS NEWSLETTER

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TUFFp Talk

New Project Assistant Hired!

I would like to take this time and introduce myself as the new Project Assistant for Fluid Flow Projects. I have been working at The University of Tulsa since October 1994 in Drilling Research Projects. When this position opened I could not resist the opportunity to work with Dr. Brill and students from different countries of the world. One of the exciting aspects of this position is working in a multi-cultural atmosphere not only within Fluid Flow Projects but interaction with our member company representatives. My background includes nine years of restaurant managerial experience with McDonald's Corporation which gave me a wide array of experience in marketing, public relations, personnel, and purchasing.

I have lived in Tulsa for the last fifteen years. I have my Associate's Degree in Business Administration from Tulsa Junior College and will be attending Northeastern State University to pursue my Bachelor's Degree in Business Marketing. My hobbies include reading, spending time with family and friends, and traveling. Some of my traveling adventures have taken me to Argentina, Mexico, and cruises throughout the Carribean. My next excursion will be to New York City in February.

Marjel Hamlin, New Project Assistant

TUFFP Financial Status Remains Excellent

Sincere appreciation is expressed to all TUFFP member companies for their continued financial support and understanding when we increased membership fees to $27,000 for 1996. No companies canceled their membership for 1996 as a result of the membership fee increase.

A concerted effort has been made to follow up on invoicing and payment problems for companies who have not paid their membership fees for 1994 or 1995. At this time, 2.5 companies have not paid their 1994 membership fees; 6 have not yet paid their 1995 membership fees. All of these companies have been contacted and we do not anticipate any problems in receiving their payments. As of January 16, 1996, only 3 companies have paid their 1996 membership fees.

Expenditures for 1996 are on schedule and follow the budget that was presented to member companies at the November 1995 Advisory Board meeting. A detailed status report on TUFFP's financial status will be reported at the May Advisory Board meeting. A preliminary analysis of probable future expenditures indicates that it will not be necessary to increase membership fees for 1997.

Reports Scheduled for Distribution

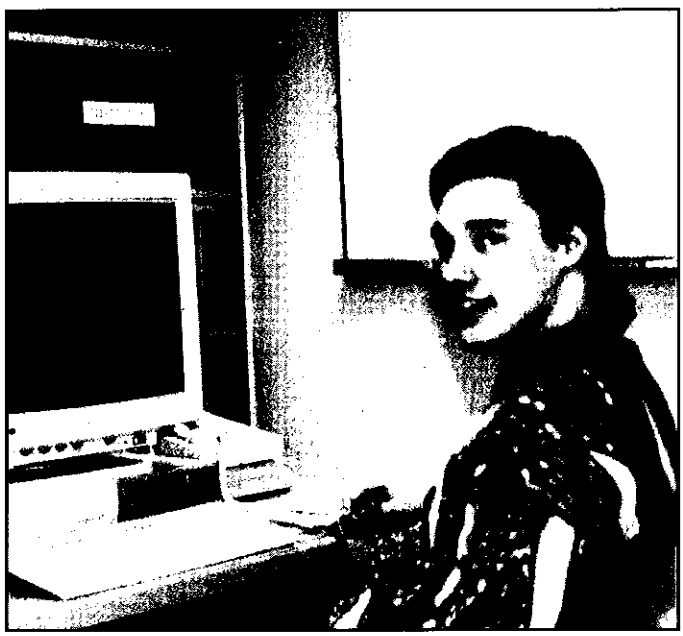
During January and February, several reports will be distributed to TUFFP members. The first of these is volume 4 of "Recent Publications" which had previously been scheduled for distribution in August. This distribution was delayed so that the latest publications from TUFFP staff could be included. In addition, the following research reports will be distributed.

- "Oil-Water Flow Patterns in Horizontal Pipes" by Dr. Jose Luis Trallero
- "A Study of Intermittent Flow in Downward Inclined Pipes" by Dr. Jiede Yang
- "A Unified Model for Stratified-Wavy Two-Phase Flow Splitting at a Reduced Tee Junction with an Inclined Branch Arm" by Srinagesh Marti

A request has been submitted to the Gas Research Institute for permission to distribute the final report on "Experiments for Liquid Transport in Gas Transmission Pipelines". This report was completed in 1995 as part of the PCB migration project.

TUFFP Changes Computer Manager

Jaime Garces-Perez will complete his M.S. degree in Computer Science in January and has made a decision to return to Ecuador to work. Jaime has taken excellent care of the TUFFP networks, and performed installation and maintenance of various software packages, distribution of data and software to member companies, and other tasks for the past two years. We are now in the process of training Brandon Land to take care of some of these tasks. Brandon is a junior in Computer Science and should be available to serve as our computer manager for at least two years.



Brandon Land, Computer Resource Manager

In addition, a Research Assistantship funded half by TUFFP and half by the Paraffin Deposition JIP will be offered to Mrs. Liming Zhu, who is pursuing an M.S. degree in Computer Science at The University of Tulsa. Mrs. Zhu will develop the GUI for the Conoco Paraffin Deposition model that well be offered to interested WAX JIP members. She will also assist with developing the database structures for the WAX JIP and various TUFFP projects, and with the Stanford University project described elsewhere in this newsletter.

TUFFP to Add Technician this Spring

Over the next three years, the Paraffin Deposition JIP will utilize approximately 75% of the available time for the current two TUFFP research technicians. Approximately April 1, 1996, it will be necessary to hire an additional technician to satisfy the needs for various TUFFP projects. We hope to find a technician that has capabilities in both mechanical and electronics areas.

TUFFP Membership Remains Stable

One company, Baker Jardine & Associates, terminated their membership in TUFFP for 1996. Discussions are underway with several companies that have expressed an interest in TUFFP to determine if they might become members for 1996. A list of 1996 members appears on a following page.

Advisory Board Meetings Scheduled

The next TUFFP Advisory Board meeting will be held May 14 - 15, 1996 at the Doubletree Hotel at Warren Place in Tulsa, Oklahoma. A request for information form is enclosed with this newsletter, together with information on hotel reservations and travel to and from the airport. Persons attending the Advisory Board meeting should complete the form and return it to us as soon as possible.

The Advisory Board meeting will begin at 8:30 a.m. on Wednesday, May 15, 1996 and will adjourn at 4:30 p.m. A pre-meeting reception will be held on the 19th floor of the adjacent Two Warren Place building from 6:00 - 8:00 p.m. on Tuesday, May 14, 1995. A tour of both TUFFP and Paraffin Deposition test facilities will be conducted on Tuesday afternoon from 3:00 - 4:30 p.m.

Following is a summary of the dates for the May 1996 Advisory Board meetings of other cooperative research programs at The University of Tulsa.

TUDRP	May 13, 1996
TUPREP	May 13, 1996
TUFFP	May 15, 1996
TUALP	May 16, 1996
TUSTP	May 17, 1996

TUFFP Advisory Board meeting brochures will be mailed to all members prior to the meeting. The brochure will contain sufficient information to help each attendee actively participate in discussions on current and future research projects, financial matters and operating procedures. A brochure containing slide copy for all presentations will be distributed at the meeting but will not be mailed to members.

Participation Probable in Joint TUFFP/Stanford University Database Project

Dr. Brill met with Dr. Khalid Aziz at Stanford University in January to further discuss the possible joint project with Stanford University to create a user-friendly multiphase flow database that uses Microsoft Access 2.0 on a windows platform. Stanford has already created the frame work for the database using the TUFFP Well Databank and a modified University of Calgary pipeline databank. Over the next few months, we will experiment with the existing database, identify

candidate data from past TUFFP experimental research projects that could be added to the database, and make a final decision on whether or not to participate. The major benefit of participating for TUFFP member companies would be to have our data available on a much easier to use format.

"Slug Tracking In Hilly Terrain Pipelines" Joint Industry Project (JIP)

A preliminary proposal and an interest ballot for the JIP were sent to 37 companies. As indicated in the proposal, this JIP will be a nonprofit, cooperative, industry-university research project undertaken by The University of Tulsa in collaboration with Tel-Aviv University. This project is a major undertaking for both The University of Tulsa and Tel-Aviv University and will require the combined expertise and experience of both universities to accomplish the objectives stated in the proposal. A coordinated study is described in the proposal to yield solutions to several practical problems encountered in multiphase hydrocarbon transportation through hilly terrain pipelines.

Originally, an initial meeting of the proposed JIP was tentatively scheduled at The University of Tulsa on February 16, 1996 to discuss all aspects of this project among potential participants. The meeting is postponed and will be held at a date closer to the TUFFP Advisory Board meeting to increase potential company participation. The possible dates are May 14, 1996 or May 16, 1996. We have started to receive responses from companies. Early results show that 6 companies indicate an interest, and would like to participate in the initial JIP meeting.

New Research Assistants Join TUFFP

Two new research assistants have joined TUFFP during the 1995 - 1996 academic year. Mr. Weihong Meng from the University of Petroleum in China arrived in August, 1995 and immediately entered the English Institute at The University of Tulsa. He will soon be assigned a research topic from one of the top priorities emerging from the TUFFP Questionnaire last summer. Nobutoshi Shimizu from Japan began his Master's degree program in January. He is fully sponsored by JAPEX and has recently been on loan to JNOC. Mr. Shimizu hopes to be assigned a research project in the area of transient multiphase flow.

It now appears that Mr. Eissa Al-Saffar from Kuwait will not begin his M.S. degree until later in 1996. He received a B.S. degree in Petroleum Engineering from University of Tulsa in May, 1995 and returned to Kuwait to work with the University of Kuwait and seek financial support for them to fund an M.S. and Ph.D. program at The University of Tulsa. His interest is in multiphase flow through pipes and if he arrives his research would be funded by TUFFP.

Weihong Meng checks readings on Roto flow meter.

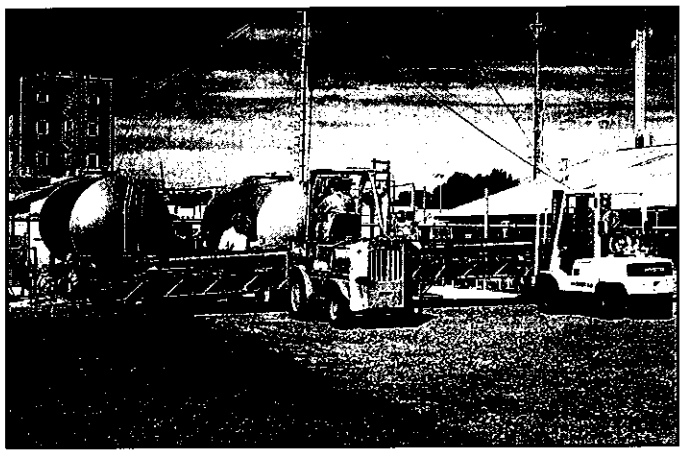
A request has been received from another outstanding petroleum engineering undergraduate student who would like to pursue an M.S. degree in TUFFP or on the Wax JIP beginning in the Fall semester, 1996. This student, Hans Jacob Lund, from Norway is one of the top undergraduate students in the department and would make an excellent addition to our research group.

Nobutoshi Shimizu checks out LabView software package.

Paraffin Deposition JIP Update

Significant progress has been made on the WAX JIP since it was initiated in May 1995. Two more companies, NKK of Japan and the Oil & Natural Gas Commission of India have joined the JIP. Statoil has terminated its membership for 1996. Several other companies are still considering joining and no penalty fees will be charged at this time for joining late. Negotiations are also underway with IFP to waive their membership fee in lieu of in-kind fluid characterization work at a value exceeding the membership fee.

In response to an RFP, eight proposals were received for performing work on multiphase heat transfer in flowlines and wellbores. After careful evaluation, the proposal from Oklahoma State University was selected for this task. Also in response to an RFP, eight proposals were received for conducting fluid characterization tests on waxy crude oils and a condensate. After careful evaluation of these proposals, Marathon Oil Company was chosen for this task with some of the tests being subcontracted to DB Robinson.

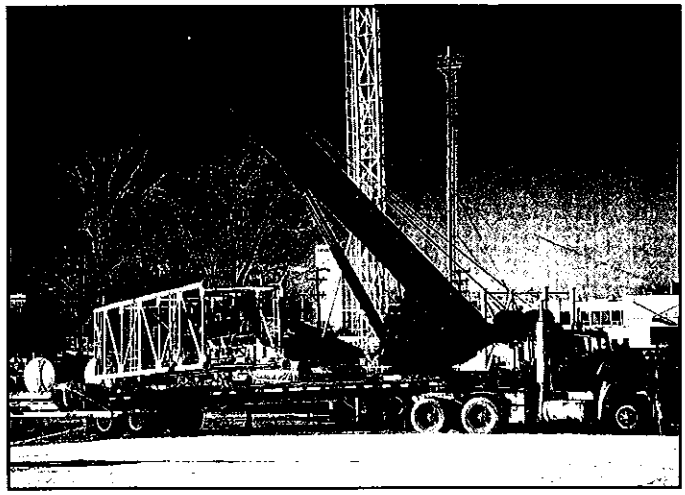


Arrival of ARC/Petro-Canada flow loop.

An extensive literature review has been completed on paraffin deposition studies for both single phase and multiphase flow through pipes. A reliable technique has been developed to accurately measure the circumferential and longitudinal wax thickness distributions and the total deposition in the flow loops. At this time, it is not clear whether this technique will become the primary measurement technique or a calibration method and a search continues for a non-intrusive continuous recording device.

The Petro-Canada/Alberta Research Council horizontal, single phase flow paraffin deposition test facility was moved from Edmonton, Alberta, Canada to The University of Tulsa last fall. In February, after all concrete slabs have been placed, this flow loop will be reassembled. Single phase deposition testing is scheduled to begin in April, 1996.

A conceptual design for the test sections to be used in the multiphase flow loop has been completed. Liquid storage tanks were identified and purchased, and an appropriate sampling/transfer technique has been developed. A contract was let for the tower and booms, and for placement of concrete slabs. Installation of the tower and booms took place in late January. A design for an instrumentation/shop building is nearing completion and we anticipate having this 2000 square foot facility available for occupancy in May.



Erection of new paraffin deposition tower.

The black oil and condensate samples to be used in the study have been selected. The black oil will come from Mobil's S. Pelto field and the condensate will come from Shell's Garden Banks field. Separator samples from the Mobil S. Pelto well for use in the PVT/Fluid Characterization study were obtained during the last week of December. A data trade has also been negotiated with DeepStar and a Letter of Agreement has been signed by both parties. A Letter of Agreement has been developed that would permit software vendors to participate in the JIP.

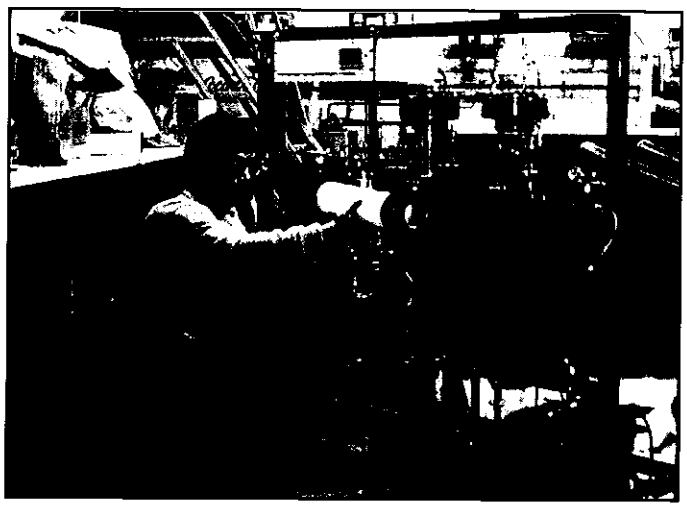
A literature survey for solid-fluid equilibrium flash data has produced a substantial amount of data which are being entered into computer files for future testing. Several models have

Bazlee Matzain inspecting single phase praffin deposition flow loop.

now been compiled from the literature and from member companies and their evaluation has begun.

At this time, one student is working on the JIP, Bazlee Matzain of Petronas, who is pursuing a Master's degree and will probably receive approval from Petronas to pursue a Ph.D. degree on the project. In addition, Petronas will send a visiting scholar to work on the project for four months this summer. Also, Elf Aquitaine plans to send a student who would be assigned to the Wax JIP in late 1996. Other students will be recruited to work on the project as needed.

The next Advisory Board meeting for the Wax JIP will be held April 25, 1996, immediately following the SPE/DOE Enhanced Oil Recovery conference in Tulsa. A tour of the Paraffin Deposition test facilities will be held on Wednesday afternoon April 24th and a reception for attendees of the Advisory Board meeting will follow at the Doubletree Hotel at Warren Place. The Advisory Board meeting will convene at the Doubletree Hotel at approximately 8:00 a.m. on April 25th.



Tom Chen working on the prototype of wax deposition measurement devices.

Calendar for 1996 Two-Phase Flow Technical Meetings

Jan. 29 - Feb. 2	Energy Week Conference & Exhibition, ASME, Houston, Texas
March 5 - 7	International Petroleum Conference and Exhibition of Mexico, Villahermosa, Mexico
April 16 - 17	SPE European Production Operations Conference & Exhibition, Stavanger, Norway
April 23 - 26	SPE Latin American /Caribbean Petroleum Engineering Conference, Port-of-Spain, Trinidad
April 25	Paraffin Deposition Advisory Board Meeting, Tulsa, Oklahoma
April 28 - 30	SPE Mid-Continent Gas Symposium, Amarillo, Texas
May 6 - 9	Offshore Technology Conference, Houston, Texas
May 15	TUFFP Advisory Board Meeting, Tulsa, Oklahoma
May 16	TUALP Advisory Board Meeting, Tulsa, Oklahoma
May 17	TUSTP Advisory Board Meeting, Tulsa, Oklahoma
May 19 - 24	Forum Series in Asia Pacific "Production and Handling of Waxy Crudes/Condensates", Nusa Dua, Indonesia
May 20 - 24	TUFFP Short Course
July 7 - 11	1996 ASME Fluids Engineering Conference Design and Operation of Wet Gas Production and Transportation Systems, San Diego, California
Oct. 6 - 9	SPE Annual Technical Conference & Exhibition, Denver, Colorado
Oct. 10	Paraffin Deposition Advisory Board Meeting, Littleton, Colorado
Oct. 23 - 25	28th Annual PSIG Meeting, San Francisco, California
Nov. 14	TUFFP Advisory Board Meeting, Tulsa, Oklahoma
Nov. 17 - 22	1996 International Mechanical Engineering Congress & Exposition (IMECE), Atlanta, Georgia
Nov. 18 - 20	2nd International Conference and Exhibition on Horizontal Well Technology, Calgary, Alberta, Canada

May 1996 Short Course Scheduled

The TUFFP short course "Two-Phase Flow in Pipes" is scheduled to be taught again in Tulsa, Oklahoma at the Doubletree Hotel at Warren Place May 20 - 24, 1996.

The course will again be taught be Dr. Brill and Dr. Sarica. The purpose of this course is to give participants a well-grounded understanding of the fundamentals of two-phase flow through pipes and restrictions. Completed and current TUFFP research projects permit teaching the latest techniques for designing multiphase flow piping systems for the production and transportation of oil and gas. Upon completion, the participants will be able to apply knowledge gained to design fluid flow conduits encountered in petroleum, natural gas, and chemical engineering operations.

The following pricing schedule will be used for the 1996 short course.

Member Company Fee Schedule
$950 per person - regular tuition
$850 per person - group discount

Non-Member Company Fee Schedule
$1,445 per person - regular tuition
$1,195 per person - group discount

We urge member companies to enroll engineers as soon as possible to assist us in planning for the course. If an insufficient number of enrollments is received by May 1, 1996, the course will be canceled. Members can enroll by contacting the Continuing Education Department at The University of Tulsa (918) 631-2347, sending a fax to (918) 631-2154 or e-mail to conted_cee@utulsa.edu.

ICON ALLEY

Since the startup of the Wax JIP, it has become impossible to separate many computer decisions that impact on both Wax and TUFFP. As a result, in this edition of ICON ALLEY you will get an overview of everything falling in the TUFFP/Wax JIP realm.

Hardware

A major hardware decision during the last quarter was to purchase a new CadJet™ Plotter. In the past we have prepared all contract documents for new test facility construction on 17 x 22 in. drawings. With the new plotter we can create E-size drawings (33 x 42 in.). We can also produce PERT or CPM charts for scheduling tasks on the Wax JIP. Jerry Wilson is now preparing many construction working drawings for the Wax JIP and appreciates having a larger format available. Although far from the top of the line in plotters, the CadJet™ produces excellent drawings and also gives us a color option for presentation documents.

We are anxious to get member companies feedback on our CD ROM data distribution. The new CD ROM mastering and copying drive has made data distribution more compact, durable and requires less time to generate data copies.

An interesting new hardware item purchased is the Newton™. Two of these PDA's (Personal Digital Assistants) were purchased in December. Dr. Brill and Jerry Wilson are running the new devices through their paces to evaluate the use of PDA's to improve efficiency. With the new 2.0 operating system on the Newton™, handwriting recognition is finally a reality. Many of you may have seen the Doonsbury cartoons digging the PDA's handwriting recognition when the devices were first introduced. They have come a long way since then.

Dr. Brill has traded his 68030 Duo 250 (black & white) for a 68040 Duo 280c (color)! The docks we have will work with this new machine and it should bring Jim up, at least a notch, in speed until the Power Mac Duo's are available and reliable. We have also added one additional Gateway "Pentium Class" computer which will be utilized by Dr. Christi Patton for work on the Wax JIP.

Software

A few new software items were picked up at the MacWorld Expo in January. One called Timbuktu™ will enable us to make NetScape™ connections to the Internet from our home computers. As it stands now, we can access E-Mail from home offices utilizing Eudora™. However, we have no home access using NetScape™. Hopefully this will enhance our access to the Internet.

Another new software package is Route 66™. This should be helpful in planning road trips. The latest version covers all of the North American continent. A new macro program called One Click™ should speed up many routine operations on our computers. Dr. Brill is testing this to determine how extensive the program should be utilized. We have also upgraded Microsoft Project™ to version 4.

Training/MacWorld Expo

Dr. Brill and Jerry Wilson attended the MacWorld Expo in San Francisco in January. Many exciting new hardware and software items were well presented at the Expo. Presentations by factory reps on the latest releases of Microsoft Office™, Canvas™, several CAD packages, Claris FileMaker Pro™, several multimedia packages, and numerous network and utility software were attended.

One of the major benefits of attending the Expo was to see and look at the many new mass storage devices. There are so many options that it is difficult to determine which formats will prevail. One of the most interesting removable devices we investigated was the Iomega Jazz™ drive with a removable disk holding one gigabyte. This device comes in many configurations (1-disk, 2-disk, 4-disk, and arrays). It appears to have broad support and acceptance and we plan to purchase one of these drives for evaluation. With the one gig size and very quick access and data transfer, this could be the storage media of choice for the large amounts of data now collected with fast LabView cards and computers.

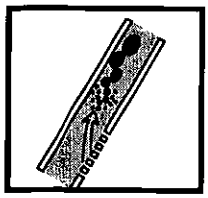
Another development we observed was the new direction of LabView™ data acquisition cards. The new Mac's and almost all DOS computers have PCI expansion slots rather than the slower NuBus type. The LabView™ people confirmed that their company is now heading in the PCI direction. This technological advance is a major consideration in the purchase of new computers.

We also visited with vendors making expansion cards for the Mac that would give us DOS/Windows capabilities without purchasing a complete computer. These cards are in the "Pentium™ Class" now and should let us get double duty out of our Macs without loss of our network and E-Mail flexibility. Dr. Cem Sarica will probably be the first TUFFP person to evaluate these cards.

Of course, one of the main topics of discussion at the Expo was the State of the Mac. The Apple™ Vice President for the Americas gave an inspirational keynote address. However, we are keeping an ear to the ground on Apple's progress in reorganization and developing new hardware and software platforms.

Research Progress

REPORTS



Oil-Water Flow Patterns in Horizontal Pipes

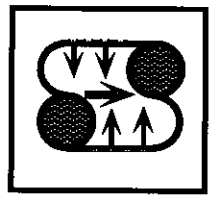
Following is the abstract in the final report on this project. The report is scheduled for distribution in February 1996.

ABSTRACT

Oil-water flow pattern transitions in horizontal pipes have been studied both experimentally and theoretically. A new state-of-the-art, gas-oil-water test facility was designed, constructed and operated. A transparent test section (1.9735 in. ID x 51 ft long) can be inclined at any angle, to study both upward and downward flow simultaneously. Mineral oil and water were the working fluids ($\mu_o/\mu_w = 29.6$, $\rho_o/\rho_w = 0.85$ and $\sigma = 36$ dynes/cm @ 78° F). Only horizontal flow tests were conducted.

A new classification for oil-water flow patterns based on published and acquired data is proposed. Six flow patterns were identified and classified into two categories: Segregated flow and Dispersed flow. Stratified flow and stratified flow with some mixing at the interface (ST & MI) are segregated flow patterns. The dispersed flow can be either water dominated or oil dominated. A dispersion of oil in water over a water layer and an emulsion of oil in water are water dominated flow patterns. An emulsion of water in oil and a dual dispersion are oil dominant flow patterns. Pressure drop decreases when the transition to dispersed flow is crossed. Conductance probe data and high speed photographs are adequate flow pattern identification tools while wall pressure fluctuations are not. Slippage is only relevant for segregated flow patterns.

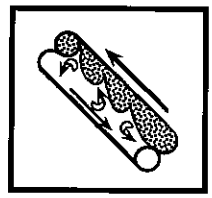
The oil-water flow pattern transitions for light oils are predicted using the two-fluid model and a balance between gravity and turbulent fluctuations normal to the axial flow direction. Linear and non-linear analyses reveal that the stratified/non-stratified transition must be addressed with the complete two-fluid model. Stratified flow is predicted by the viscous Kelvin-Helmholtz analysis while inviscid Kelvin-Helmholtz theory predicted the ST & MI flow pattern. Both the viscous Kelvin-Helmholtz analysis and structural stability criterion are satisfied simultaneously. For the dispersed flow pattern, the predicted drop sizes from the Hinze and Levich models are modified in order to account for the effect of the dispersed phase concentration. The controlling parameter for the coalescence phenomena is the water fraction. The model performance is excellent and compares well with published data. Moreover, the model gives reasonable predictions for inclined flow.



Single -Phase Flow Behavior in Horizontal Wells

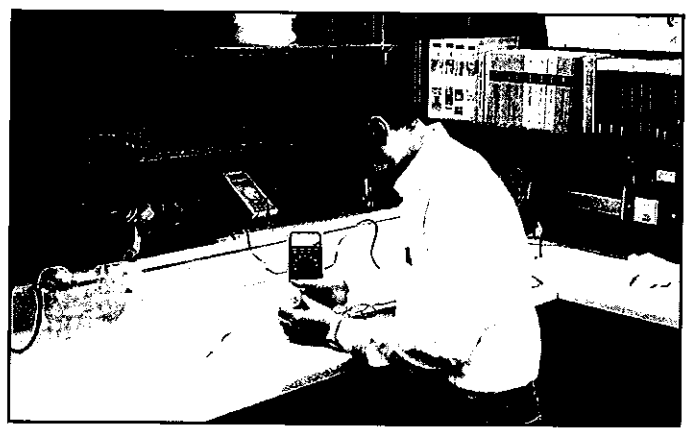
Horizontal wells can have very complex flow geometries, in part due to interaction between the main flow stream and the influxes along the wellbore, and also due to completion type. In the first phase of this project, a new single phase flow generalized friction factor expression for a single perforation horizontal well was developed using the principles of conservation of mass and momentum. A simple correlation for the horizontal well friction factor was then developed by applying experimental data to the generalized friction factor expression.

In the second phase of this project, single phase flow behavior in horizontal wells with uniform fluid injection from multiple perforations is being investigated. Data acquisition, processing and analysis for the case of a 1.0-in. diameter pipe with 5 perforations per ft (geometrically similar to a 6.0-in. diameter casing perforated 1 shot per ft) has been completed. The test facility was then modified to permit acquiring data for a 1.0-in. diameter pipe with 20 perforations per ft (geometrically similar to a 6.0-in. diameter casing perforated 4 shots per ft). Data acquisition with the new test section is currently underway and results will be presented at the May Advisory Board meeting.



Oil-Water Flow Patterns in Vertical and Deviated Wells

The multiphase flow of oil and water in wells and pipelines is a significant problem that has received little attention in the literature. Oil field problems associated with the identification of flow patterns in oil-water systems include interpretation of production logs, pressure drop calculations, and design and modeling of artificial lift installations.

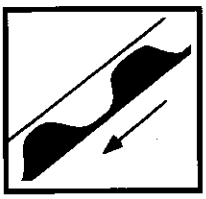


José Flores testing new instrumentation designed at TUFFP for oil/water flow loop.

The objectives of this research project include acquiring experimental data at various flowing conditions and high inclination angles typical of vertical and deviated wells using a mineral oil and water, and developing mechanistic models to predict the flow pattern transitions.

The scope of the research project, a detailed review of the literature, and the oil-water flow database for inclined pipes were discussed extensively at the November 1995 Advisory Board meeting. In recent months, work has concentrated on designing modifications to TUFFP's oil-water flow facility and data acquisition program, conceiving new instrumentation to install in the test line, and outlining the experiments to be conducted.

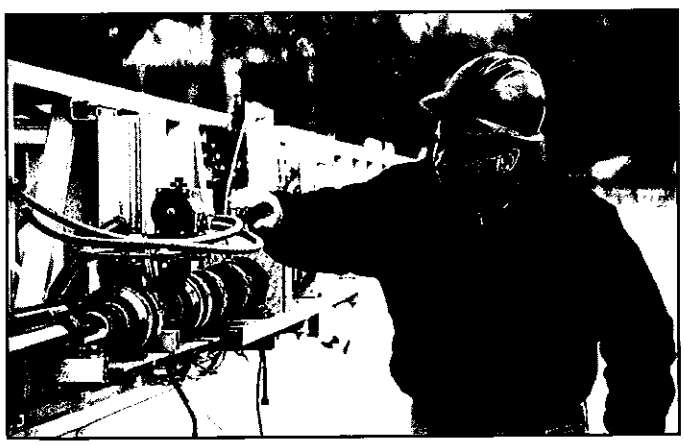
Activities for the coming months will include implementing the modifications to the test facility and data acquisition program, installing new instrumentation, and acquiring the data as soon as weather permits. It is anticipated that a significant portion of the experimental work will be available for presentation at the May Advisory Board meeting.



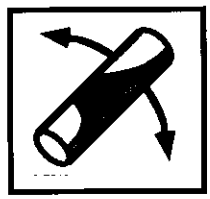
Slug Dissipation in Downward Flow

Slug Flow is a common occurrence in hilly terrain pipelines. The standard engineering method for performing multiphase flow calculations for a pipeline is to divide the pipeline into various sections of constant slopes, and apply flow models to simulate flow behavior in each section. This approach does not consider the interaction between uphill and downhill sections. An important consequence of this interaction is carryover of large slugs into downhill sections that were created in uphill sections, even though modern flow pattern prediction models indicate that stratified flow should exist in the downhill sections. The TUFFP objective for this project is to conduct an experimental and theoretical study to investigate slug dissipation in a downward section of a hilly terrain pipeline.

Since the last Advisory Board meeting, a conceptual design of the test facility has been completed. The inclined flow test facility will be modified for this project. Modifications will start in early March and will include installation of 12 new capacitance sensors. Currently, a complete literature survey is underway. Results of the survey will be presented at the May 1996 Advisory Board meeting.



Miguel Paz checks the quick closing valves used for dynamic calibration.



A Study of Downward Intermittent Flow in Inclined Pipes

Following is the abstract in the final report on this project. The report is scheduled for distribution in February 1996.

ABSTRACT

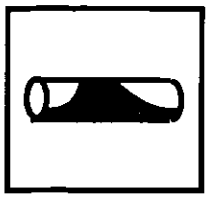
The downward simultaneous flow of gas and liquid is often encountered in hilly terrain pipelines and steam injection wells. Most of the available methods for predicting the behavior of gas-liquid two-phase flow in pipes have been developed for horizontal, upward vertical or upward inclined pipes.

This study experimentally and theoretically investigates co-current steady state slug flow in downward inclined pipes. The TUFFP inclined two-phase flow test facility was modified to acquire data for the entire range of downward inclination angles. A series of slug flow experiments were conducted with an air-kerosene system in a 2-in diameter, 75-ft long transparent PVC pipe installed on an inclinable structure.

Liquid holdup and pressure drop measurements were obtained for downward inclination angles from 0° to -90° at different flow conditions. Data processing showed that fully developed slug flow does not exist from -50° to -90°. Slug characteristic parameters were investigated based on the acquired data for different inclinations from 0° to -30°.

Based on 48,510 slug samples and three independent measurements with three capacitance sensors for each sample, a correlation was obtained for slug liquid holdup, and a theoretical model and a correlation were developed for slug translational velocity. Slug length distribution was studied. Based on 21 distribution functions, a Lognormal distribution was found to best fit all the experimental data. The two characteristic parameters for the Lognormal distribution were correlated with superficial gas and liquid velocities and inclination angles (0° to -30°). Another slug length distribution was also obtained for the horizontal configuration, based on 13,000 slug samples. Equations for mean and design slug length were derived from the Lognormal distribution function.

A comprehensive mechanistic model has been developed for the prediction of the detailed slug structure, and subsequently the pressure gradient, based on a unit cell model, and mass and momentum conservation equations. The evaluation of the mechanistic model showed that the model can predict pressure gradient with an error of less than 15%. These predictive equations and models can be used in the design of downward inclined pipelines operating in intermittent flow.



Slug Length Distribution and Liquid Holdup in Horizontal Pipe

Data collected during 62 experimental tests on the TUFFP 3-inch flow loop have been processed. These tests cover various combinations of mixture and superficial gas velocities ranging from 3.0 to 28 and 0.5 to 7.09 ft/s, respectively.

Slug length growth has been detected between measuring stations approximately 530 ft apart. The slug length distribution has been compared with Lognormal and inverse-Gaussian distributions. Lognormal is the better fit based on results of the Anderson-Darling "goodness-of-fit" test. Liquid holdup in the slug body follows a similar trend as in previously published works. Pressure gradient shows an almost linear increase as superficial gas velocity increases at constant superficial liquid velocity. Slug translational velocity indicates a significant drift velocity.

Analysis of the processed data is continuing and a final report will be presented at the May 1996 Advisory Board meeting.

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Robert Marcano observing slugs through transparent section between capacitance sensors during testing.

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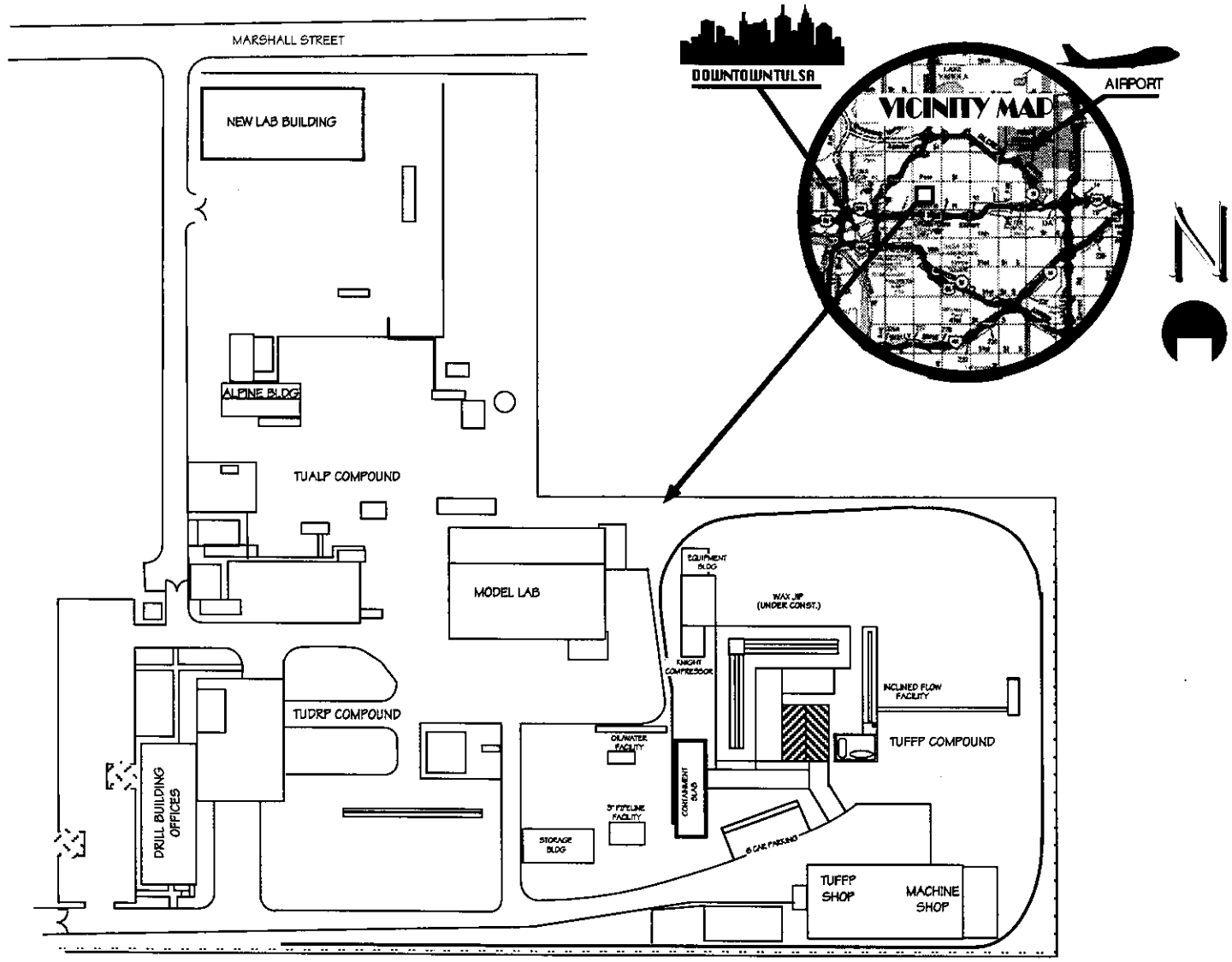

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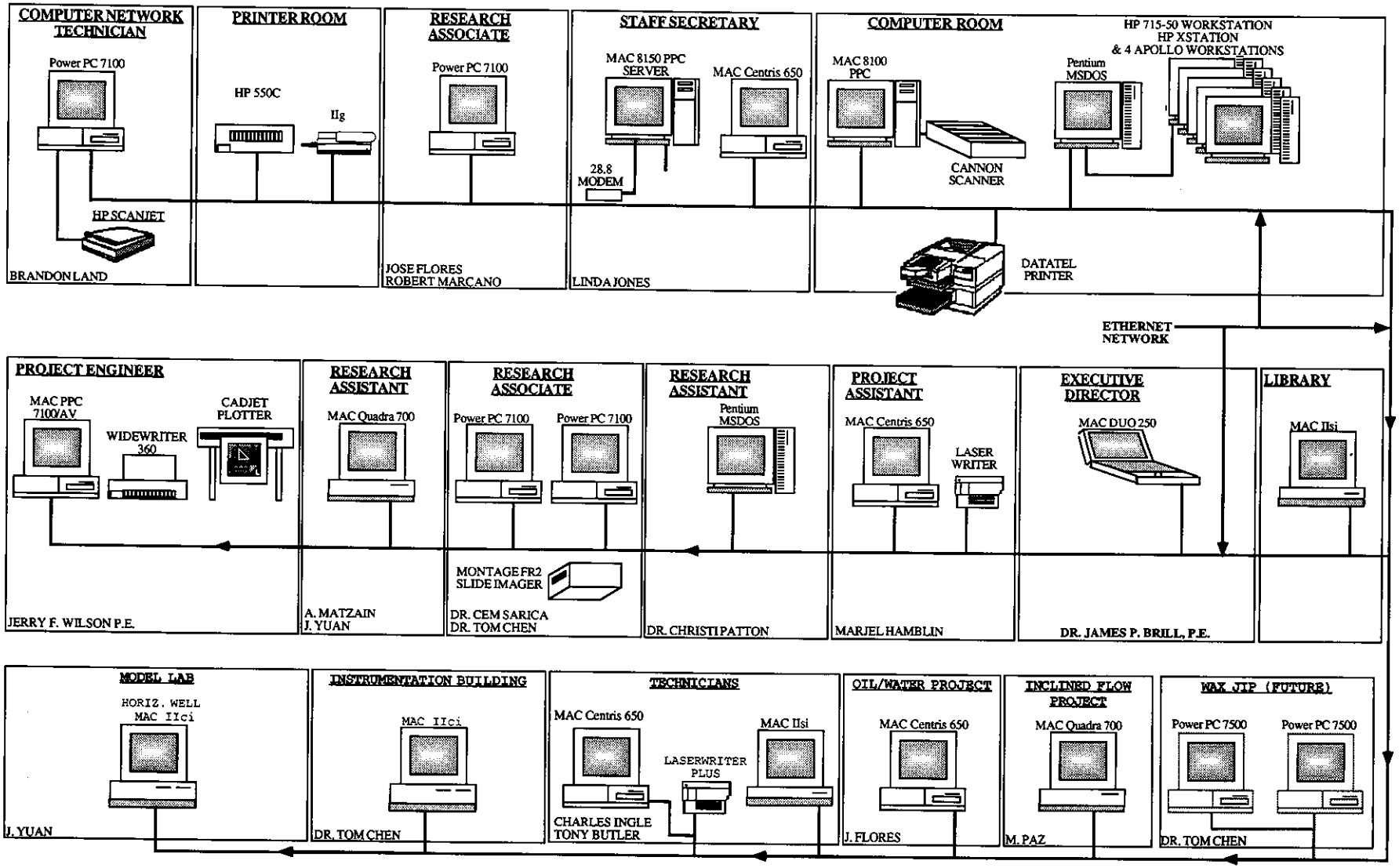
TUFFP/WAX JIP COMPOUND SITE PLAN SPRING 1996

TUFFP/WAX JIP COMPUTER NETWORK



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